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A methodology for the assessment of local-scale changes in marine environmental benefits and its application

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Abstract

Considerable effort has been applied in developing typologies and conceptual frameworks for the assessment of ecosystem services that consider a broad suite of services and benefits. Local-scale planning decisions are required by the existing Environmental Impact Assessment process to take account of the implications of a development on a range of environmental and social factors, and could therefore be supported by an ecosystem services approach. However, empirical assessments at a local scale within the marine environment have focused on only a single or limited set of services. This paper tests the applicability of the ecosystem services approach to environmental impact appraisal by considering how the identification and quantification of a comprehensive suite of benefits provided at a local scale might proceed in practice. A methodology for conducting an Environmental Benefits Assessment (EBA) is proposed, the underlying framework for which follows the recent literature by placing the emphasis on ecosystem benefits, as opposed to services. The EBA methodology also proposes metrics that can be quantified at local scale, and is tested using a case study of a hypothetical tidal barrage development in the Taw Torridge estuary in North Devon, UK. By suggesting some practical steps for assessing environmental benefits, this study aims to stimulate discussion and so advance the development of methods for implementing ecosystem service approaches at a local scale.

1. Introduction: The Evolution of Ecosystem Service Frameworks

Ecosystem services approaches have developed with the aim of providing a common language and a transparent framework for quantifying the ecological, social and economic trade-offs that must be evaluated in development decisions (Granek et al., 2009). The Millennium Ecosystem Assessment (MEA, 2003) proposed a classification of provisioning, regulating, cultural and supporting services. Subsequent frameworks have sought to more clearly distinguish between services and benefits on the basis that evaluating benefits avoids double counting (Fisher et al., 2009). Thus, The Economics of Ecosystems and Biodiversity (TEEB, 2010) and the UK National Ecosystem Assessment (2011) have both developed typologies that attempt to distinguish between services providing direct and indirect benefits. Other authors have sought to expand classification frameworks so that, as well as ecological parameters, they include benefits derived solely from the abiotic elements of the environment such as

the use of space for transportation (Balmford et al., 2008; Saunders et al., 2010). Further refinements to ecosystem service classifications have been suggested under the Common International Classification of Ecosystem Services (Haines-Young and Potschin, 2013), whilst the inclusion of cultural services has been the topic of a recent debate in the literature (Daniel et al., 2012; Kirchoff, 2012; Chan et al., 2012).

The operational usefulness of conceptual frameworks can only be determined by applying them in the field. Conceptual frameworks include a broad suite of ecosystem services, but empirical research tends to focus on services individually or on a limited set (Rees et al., 2012; Mangi et al., 2011; Luisetti et al., 2011; Pittock et al., 2012; Balvanera et al., 2006). Further studies that attempt simultaneous assessment of a large suite of ecosystem services are required as lessons learned from such empirical application will help to aid development of the ecosystem services approach as a practical tool for supporting decision making in natural resource management.

In this paper we propose a framework methodology that supports application of the ecosystem services concept to local environmental impact appraisal, and then explore implementation of the methodology through a case study of a hypothetical tidal barrage in an estuary in south west England.

2. Developing a tool for local environmental impact appraisal

The context of this research is to evaluate the potential for ecosystem service assessments to support decision-making with respect to a specific local-level intervention. Across Europe, appraisal of the environmental impact of a development is currently governed by the Strategic Environmental Assessment (SEA) Directive (Directive 2001/42/EC) and the Environmental Impact Assessment (EIA) Directive (Directive 2011/92/EU), for, respectively, public programmes and individual projects. Both are procedures that seek to ensure that environmental implications are appropriately considered in decision-making and similar policy and legal tools are used internationally.

The SEA and EIA Directives are conceptually well aligned with the ecosystem services approach since they both consider the environment as more than its ecological parameters, and contain explicit reference to the need for evaluations to consider people, material assets and cultural heritage. The procedures they prescribe for the appraisal of environmental impacts already include assessment of the effects of developments on a wide range of environmental, social and economic benefits. However, in categorising the parameters to be assessed, the approach taken in the SEA and EIA guidance has not been systematic. To use tidal barrages as an example (as the subject of the case study presented in Section 4 below), a SEA was carried out as part of a recent feasibility study on a potential Severn Barrage (Parsons Brinckerhoff, 2010), and further guidance for compiling EIAs for tidal barrages has also been produced (Environment Agency, 2002). The categorisation used within both the SEA and EIA guidance causes duplication, with, for example, noise, flood risk and water

quality listed as significant issues in more than one SEA topic, and visual amenity appearing in two EIA categories.

Also, the SEA approach as applied to the Severn Estuary does not lead easily to the step of valuation, which can facilitate decision-making by quantifying the impacts using a common metric, thus supporting cost-benefit analysis. This is because no distinction is made in presenting information on ecosystem processes (such as saltmarsh functionality), services (including water quality) and environmental benefits (for example availability of commercial fish species), and so it is not immediately apparent for which of the parameters detailed valuation should be attempted. Therefore, there remains scope to develop a methodology that ensures a systematic and comprehensive treatment of the full range of benefits likely to be affected, and facilitates an additional step of valuing these benefits to allow their quantification in a common metric. The Environmental Benefits Assessment methodology proposed below aims to address these issues in relation to specific local-level interventions.

3. Proposed Methodology for an Environmental Benefit Assessment (EBA)

The first stage of an Environmental Benefit Assessment (EBA) is to characterise the site and identify stakeholders as this is fundamental to gaining an understanding of the benefits delivered prior to the proposed development. The current situation is then described through i) compiling an inventory of the environmental benefits obtained from the site; ii) quantifying current level of delivery of each benefits; and iii) determining their relative importance. The change in the level of delivery of the environmental benefits as a result of proposed development is then examined. These steps are described in more detail below.

3.1 Definitions

The proposed methodology follows Balmford et al. (2008) and Saunders et al. (2010) by including services provided solely by the abiotic elements of the environment as well as those with an ecological basis. This ensures that the assessment can accommodate all the potential implications of a proposed infrastructure development within a single process and is in line with the SEA/EIA process, which considers benefits such as transport. The term ‘environmental services’ is used to describe this extended classification, and is defined as the conditions and processes through which natural ecosystems, and the species and abiotic characteristics that make them up, sustain and fulfil human life (adapted from Daily, 1997).

The methodology seeks to identify and quantify benefits (as opposed to the services that provide them), because it aims to facilitate ecosystem valuation. Operationally, ecosystem valuation is much simplified by considering only the ecosystem endpoint that yields a valuable benefit and not the complex processes by which it was provided, as measurement of the latter is much more complex

(Boyd and Banzhaf, 2007). Definitions that clearly distinguish between services and benefits are essential (Fisher et al., 2009), and it has been suggested that the separate term ‘ecosystem benefit’ could be explicitly defined and applied within valuation frameworks to reflect this (Wallace, 2007; Fisher and Turner, 2008). The proposed methodology will therefore also use the term ‘environmental benefit’, which is defined as the point at which a direct gain in human welfare provided by environmental services is realised (adapted from Fisher et al., 2009).

3.2 Site characterisation and identification of stakeholders

The concept of environmental benefits is anthropocentric. At the outset of any assessment it is important to understand the social, economic and cultural issues within the local area where an assessment is required, as these are integral to the realisation and perception of environmental benefits. Such understanding is gained by collating information on the socio-demographic characteristics of the local population, land use, economic activity and employment, as well as the environmental characteristics of the area (including existing environmental protection measures). Understanding the character and use of the area helps to identify stakeholders (organisations and individuals) from whom specific information can be sought. These stakeholders may not all be local; it is likely that there will often be regional, national and potentially international interest in the area.

3.3 Identifying relevant environmental benefits

A comprehensive inventory of the environmental benefits provided by the site is required at the start of any assessment, so that the full scope of potential impacts can be understood. The environmental benefits provided may be realised or transferred elsewhere (for example, carbon sequestration and the health benefits of recreation), but the EBA is concerned with the implications of a development on the supply of all benefits from the local site. Local and wider knowledge is essential in compiling an environmental benefits inventory for a particular site, requiring consultations with local stakeholders and examination of any relevant grey literature.

The creation of an inventory is facilitated by a classification framework providing a coherent categorisation of environmental benefits. In this methodology, a classification framework was developed that draws heavily on the existing literature, but aims to facilitate operational assessment in a specific context rather than provide examples to illustrate a concept. The foundation of the framework was the definition of the types of values responsible for benefit provision. This permits the inclusion of existence, bequest and option values, which form part of the Total Economic Value of an ecosystem (Barbier 1994), and also serves as a precursor to an ultimate valuation stage. For example, market prices are available for many benefits with direct use values, whilst costs to avoid or mitigate damage are often used to determine indirect use values, and stated preference techniques are required to elicit non-use values.

The value categories were then mapped onto environmental service types, as the established typologies provide a comprehensive characterisation of services that prompts the compilation of an extensive inventory of benefits. The Millennium Ecosystem Assessment (2003) typology of provisioning, cultural and regulating services was used, but supporting services were omitted, as they do not directly provide environmental benefits. An additional category of carrier services was, however, included (after De Groot, 2006), to describe the provision of space for infrastructure or transport. These broad service types were then subdivided into categories of benefits (after Beaumont et al., 2008; Balmford et al., 2008; Saunders et al., 2010).

The inventory is completed by listing, within the relevant categories, all the specific benefits provided by the site. Examples of the expected benefits from a UK macrotidal estuary have been used as an example to illustrate how the inventory could be populated (Table 1).

Table 1. An environmental benefits inventory for a generic UK macrotidal estuary

Type of value	Service type	Benefit/Value category	Examples of specific benefits
Direct Use (consumptive)	Provisioning	Food	Fish, shellfish, marine plants and algae
		Raw materials	Bait, aggregates, industrial products, biofuels
Direct Use (non-consumptive)	Carrier	Provision of space	Transport, mooring, energy installations
	Cultural	Recreation and tourism	Nature watching, angling, watersports
		Cognitive development	Education, research
		Heritage and identity	Archaeology, cultural heritage
		Psychological wellbeing	Visual amenity, inspiration
Indirect Use	Regulating	Contaminant control	Clean water and air
		Disturbance prevention	Flood and erosion control, climate regulation
Non-Use		Existence, Bequest	Knowledge that adequate habitat is available locally and will continue to be so in future
Future Use		Option	Availability for alternative future uses

3.4 Quantifying the current level of benefit delivery

A detailed evaluation of the individual benefits listed within the inventory is then required. The first stage is to identify appropriate measures by which each benefit can be effectively quantified, and then to use these to determine the level at which the benefit is currently delivered in order to establish a baseline against which the changes resulting from the proposed development can be compared. An Environmental Benefits Assessment is concerned primarily with the human perspective, and so much of this data must be obtained directly from observational data relating to the beneficiaries. It is likely that some data (fisheries and tourism statistics, for example) is already collected and held by statutory and other agencies. Other data sources include grey literature and peer-reviewed articles.

3.5 Evaluating the importance of the environmental benefits

The list of benefits provided by a particular ecosystem is likely to be extensive, and, in the absence of monetary values, the different benefits will be quantified using different metrics. To aid preliminary

evaluation, and help to inform how effort should be focused when quantifying the changes resulting from the proposed development, the importance of each benefit can be represented on an ordinal scale (high, moderate or low). Objective importance criteria are likely to be absent for many environmental benefits, so this qualitative assessment needs to be based on discussions with stakeholders that consider factors such as the number of beneficiaries and degree of management concern.

3.6 Quantifying changes in benefit delivery as a result of the proposed development

On the basis of the list of identified, prioritised potential environmental impacts of the development, the expected change in the level of each environmental benefit following the development then needs to be quantified. Environmental impact information can be obtained from strategic and project-specific environmental impact assessments published to date, as well as peer-reviewed and grey literature, and expert opinion. These changes should be quantified, indicating the levels of uncertainty around the estimates.

The current level of, and predicted changes to, each environmental benefit can be reported in the original measurement metric (such as weight of fish landed or number of participants). However, this will result in the change in benefit delivery being reported in a range of metrics. Performing the additional step of monetary valuation standardises the metric used, making more apparent the relative significance of impacts on the different benefits.

4. Applying the EBA methodology in a case study: Tidal Power in the Taw Torridge Estuary

4.1 The Taw Torridge Estuary

The Taw Torridge estuary is in North Devon in the south west of England (Figure 1). The recurrent pressure on the local authorities to consider a tidal range energy scheme was noted in the latest Estuary Management Plan (Northern Devon Coast and Countryside Service, 2010), but no detailed feasibility study has yet been undertaken. This case study is based on the hypothetical construction of a barrage crossing the Taw at Crow Point just upstream of the confluence of the two estuaries.

4.2 Empirical Environmental Benefits Assessment

4.2.1 Site characterisation and identification of stakeholders

An important group of stakeholders and beneficiaries are those people living in the closest proximity to the Taw Torridge estuary system, which was defined as the area within about 20km of the confluence of the rivers to include the tidal limits of both rivers and the main population centres of the area. The area is rural and economically deprived, and the local population is predominantly white and older than the national and regional average (Table 2). Individual stakeholders consulted included: councils and statutory agencies, watersports clubs, tourism, arts organisations, fishermen and fisher associations, conservation organisations, utility companies, the harbour master, a large shipyard, the Royal Marines, and a local business forum.



Figure 1. The location of the Taw Torridge Estuary

Table 2. Selected demographic and environmental characteristics of the area within 20km of the Taw Torridge estuary

Characteristic	Measure	References
Population size	100,000 people	ONS, 2001
Urbanisation	Low compared to the national average, but locally high in the immediate proximity of the Taw Torridge	Environment Agency, 2008
Ethnicity	99% white	ONS, 2001
Age structure	Median age is 45.5, compared to 40.0 for the South West region and 37.0 for the national average	ONS, 2001
Unemployment	Unemployment rates are higher than regional and national averages	Devon County Council 2006a,b
Earnings	Wage rates are 21% lower than the national average	Nankivell, 2010
Economic drivers	A higher proportion of the population are employed in tourism, agriculture and fishing compared to regional and national averages. In absolute terms, the latter sectors are relatively small, while tourism supports over 20,000 jobs, and was worth £375million in 2008.	ONS, 2001 Northern Devon Partnership, 2009 Nankivell, 2010
Land use	Predominantly grass and pasture, reflecting the widespread cattle and sheep farming	Environment Agency, 2008; DEFRA, 2007
Statutory environmental protection	Four Sites of Special Scientific Interest designated for bird and plantlife, coastal habitats and geological landforms; a Special Area of Conservation, a UNESCO Biosphere Reserve, and an Area of Outstanding Natural Beauty.	Natural England, 2001a, b; UNESCO, 2009; JNCC, 2002; North Devon AONB Partnership, 2009

4.2.2 Identifying relevant environmental benefits

The Taw Torridge provides a range of environmental benefits derived from provisioning, carrier, regulating and cultural services. The inventory of benefits is provided in Table 3.

4.2.3 Current level of benefit delivery and importance of environmental benefits

Data on the current levels of benefits arising from the Taw Torridge, and described in the following paragraphs, was collated from existing sources. Secondary sources (grey and peer-reviewed literature, unpublished data from statutory and other agencies, and personal communications) enabled at least partial quantification of 12 of the 31 benefits listed, although there is a low confidence level associated with much of the data (Table 3). The criteria for confidence level depended on the source of the data, how recently it had been collected, and its scope (i.e. whether it considered the entire estuary or sector, or was a partial assessment). The confidence level is awarded on the basis of the authors' judgement.

The Taw Torridge itself is not a significant source of food or raw materials, although there is the potential for greater exploitation of the shellfish beds. The estuary has one of the largest natural mussel stocks in the south west (TTEP, 1998) and has eight designated bivalve production areas (Food Standards Agency, 2010), but it is not extensively exploited due at least in part to recurrent water quality issues (TTEP, 1998). Netting for salmon and sea trout continues in the Taw Torridge, but is being phased out (CEFAS and Environment Agency, 2010), and a small number of small-scale commercial fishers use drift nets for bass and mullet within the estuary. The open sea beyond the estuary supports more significant fisheries. Skates and rays, squid, bass, whelks, lobsters and flatfish (particularly sole and turbot) are particularly important in the catches landed at local ports (MMO, unpublished data). The estuary is used by marine fish (Environment Agency, unpublished data) and is a nursery for bass (Kelley, 1986), so there is the potential for developments within the Taw Torridge to have implications for the local inshore fisheries. However, the scale of the contribution by the Taw Torridge, and its relative importance compared to other local estuaries (such as Milford Haven, Burry Port and the wider Bristol Channel) is unknown.

The most significant benefit resulting from carrier services is as a unique military facility for amphibious craft training. The military use the area between one and three times per week. Cultural services provide much greater benefits, particularly given the importance of tourism to the area. It has been estimated that tourism supports over 20,000 jobs (Northern Devon Partnership, 2009), although the specific role of the estuary and coastal area in supporting tourism is difficult to assess as there have been few detailed studies of recreational use of the Taw Torridge. However, Abell and Bromham (2009) estimated that in 2008, nearly 150,000 visitors were attracted, at least in part, by local watersports opportunities.

An indication of the uptake of recreational benefits by the local population was determined from the membership of local clubs and organisations, which suggests that angling and sailing are particularly well subscribed. Nature watching is also poorly quantified, although potentially this is an important benefit as the estuary provides opportunities to observe waterbirds, otters and occasional marine mammals. Eighty eight waterbird species including rare visitors to the UK such as the spoonbill have been recorded in the estuary (Calbrade et al., 2010).

Schools and field studies centres make educational visits to the estuary, and academic interest in the Taw Torridge is similar to that for other small estuaries in the region, although considerably less than for major, well-studied estuaries such as the Severn and Tamar. The Taw Torridge estuary contains many features of archaeological interest (Preece, 2008), including two scheduled ancient monuments (Planning Policy Unit, 2003; TTEP, 1998). Shipbuilding and fishing are extremely important to the heritage of the area (Preece, 2008; Farr, 1976; Oppenheimer, 1968), and maintaining links to this heritage supports local tourism.

The cultural heritage and the environment of the area inspire individual artists, although the best known contribution of the Taw Torridge to the Arts remains as the inspiration for Henry Williamson's 1927 novel *Tarka the Otter*. The estuary and its adjacent open coastline provide a varied seascape, with mud and sandflats, sandy and rocky shores, and the extensive dunes of the Braunton Burrows. The visual appeal of the seascapes extending from the estuary mouth has been recognised by their designation as an Area of Outstanding Natural Beauty.

The management of waste entering the Taw Torridge is a serious environmental issue, since effluent has been found to affect the quality of both shellfish (UK National Reference Laboratory, unpublished data) and bathing waters (Environment Agency, 2010). The Taw has been designated a Sensitive Area (Eutrophic) since 1998 under the Urban Waste Water Treatment Directive (DEFRA, 2008) and is also a Nitrate Vulnerable Zone under the Nitrates Directive (DEFRA, 2010). The estuarine habitats (particularly the areas of saltmarsh and mudflat and the shellfish beds) can contribute to the provision of clean water by sequestering pollutants. The regular occurrence of poor water quality suggests that contaminant supply exceeds the capacity of the ecosystem to sufficiently remediate the pollutants introduced into it.

There is a significant flood risk to settlements surrounding the Taw Torridge estuary, many of which have substantial areas classified within the highest risk category (Zone 3 in the Government's Planning Policy Statement 25) (Environment Agency, 2011). Nearly 2,000 properties are at risk in Barnstaple, 800 in Bideford and 500 in Braunton (Environment Agency, 2009). Floods also affect infrastructure including schools, hospitals, roads, railways, and electricity substations, although no

sewage or water treatment plants are thought to be at risk (Environment Agency, 2009). The most recent severe flooding event occurred in December 2012.

There is some degree of manmade flood defence along almost the entire length of the estuary, and so the role of the ecosystem has probably been superseded by these interventions. However, a policy of managed realignment has been proposed for certain parts of the estuary, which would allow previously enclosed and defended areas to revert to intertidal zones (Environment Agency, 2008; Halcrow Group Ltd, 2009). The role of the ecosystem in flood and erosion control may therefore become more important.

Air quality and climate regulation are particularly difficult to quantify as a result of the wide range of other factors (which are not necessarily marine or local) that contribute to the supply of the benefit. The global scale of climate processes suggests that the estuary, in isolation, does not provide a significant benefit. There is no data on the non-use or option use values for the estuary.

4.2.4 Quantifying changes in benefit delivery as a result of the proposed development

The construction of a tidal barrage in the Taw-Torridge would affect a broad suite of benefits (see Hooper and Austen, 2013, for a full discussion) and we report here a simple qualitative assessment of the likely significance of the impacts that could arise, identifying both the direction (positive, negative) and magnitude (high, moderate, slight) (Table 3). An empirical study involving the quantification and valuation of changes associated with hypothetical barrage developments in the Taw-Torridge will be reported separately. In the case of an actual development that is proceeding through the planning process, greater detail will be available that will allow quantification to be attempted using a combination of techniques including modelling, expert judgement and stakeholder consultation. This is the case with existing feasibility studies and EIAs, which attempt to quantify parameters such as the area of habitat lost or evaluate hydrological changes.

Food benefits would potentially decline due to the risk of mortality for fish passing the barrage. Migratory species such as salmon and eels would be most affected, although there might also be impacts on marine fish. An associated decrease in opportunities for recreational angling could also be expected. A decline in shellfish exploitation would be likely if water quality deteriorated as a result of reduced flushing, and recreational watersports users might also be affected if contaminant levels increased. Conversely, there would be the potential for watersports opportunities to increase as a result of higher water levels in areas upstream of a barrage, although this benefit could be tempered by the need for users to navigate the barrage when moving between different parts of the estuary.

The changes in water levels brought about by a tidal barrage could also bring benefits to those enjoying the view of the estuary, as individuals may prefer to see water as opposed to mudflat,

although the physical structure of the barrage itself may reduce the aesthetic appeal of the estuary. Noise levels in the proximity of the barrage would also increase. A barrage might also negatively affect wellbeing and opportunities for nature watching through the loss of intertidal area and the subsequent effects on, in particular, wildfowl and waders. The reduction in mudflat area would likely be one of the most significant impacts of a tidal barrage, but substantial benefits could accrue in other areas. In particular, a barrage would present a significant research and education opportunity, and valuable flood protection could be provided for buildings and infrastructure upstream.

Table 3. A summary of the results of the Environmental Benefits Assessment, including confidence in the data presented and the potential scale of barrage impacts

Level of importance (in terms of policy drivers and/or number of people affected): *** high, ** moderate, * low
Potential welfare impacts *Negative:* – – – high, – – moderate, – slight; *No impact:* 0; *Positive:* + slight, ++ moderate, +++ high

Environmental Benefit	Importance	Measures (types and units)	Level of delivery in the Taw Torridge estuary	References	Confidence assessment	Potential impact of barrage
<i>A. Direct use (consumptive)</i>						
<i>Food</i>						
Shellfish – shore-based harvesting	*	Landing/harvest statistics (kg/yr)	Approx 180 tonnes of mussels per season	<i>pers comm.</i> (harvesters)	Moderate	– – –
Shellfish – subtidal	**		Unquantified. Little harvesting within the estuary, but important beyond the estuary mouth		Poor	–
Eels	*		130-200kg of elver per year	DEFRA, 2010b	Moderate	– – –
Salmonids	*		423 salmon and 889 sea trout per year	Environment Agency, 2009b	Moderate	– – –
Marine fish	**		Unquantified. Small-scale commercial drift netters and recreational fishers exploit the estuary. 26 fishing boats, operating beyond the mouth, are licensed to estuary ports		Poor	– –
Marine plants	*		Unquantified, small scale		Poor	0
<i>Raw materials</i>						
Bait	*	Harvest statistics (kg/yr)	Unquantified, common		Poor	– – –
<i>B. Direct use (non- consumptive)</i>						
<i>Provision of space</i>						
Moorings	*	Number of moorings	Unknown		Poor	–
Military operations	***	Frequency of exercises	Frequent usage (e.g. 1-2 trips/ week for larger Landing Craft Utility vessel, beach driving courses twice/ month)	<i>pers comm.</i> (Royal Marines)	Good	– –
Cables and pipelines	*	Number of pipes/cables	At least one sewage pipeline, but no telecoms cables, cross the estuary	<i>pers comm.</i> (utility companies)	Moderate	0
<i>Recreation & tourism</i>						
Sea angling	***	Number of participants	4 clubs, 550 members	<i>pers comm.</i> (recreation clubs)	Poor	– – –
Wildfowling	*		1 club, 75 members		Poor	– – –
Watersports	***		8 clubs, 880 members; 149,000 visitors in 2008 attracted, at least in part, by watersports	Abell and Bromham, 2009	Poor	+ + + ¹ / – ²
Nature watching	***		Unknown		Poor	– – –
Swimming	**		Unknown		Poor	– –
Coastal margin activities	***		Unknown		Poor	–

Environmental Benefit	Importance	Measures (types and units)	Level of delivery in the Taw Torridge estuary	References	Confidence assessment	Potential impact of barrage
<i>Cognitive development</i>						
Education	**	Number of participants	Potentially 5,000+ child-visits per year	survey of local schools	Moderate	++
Research	*	Number of published papers/reports	83 papers/reports published	National Marine Biological Library (NMBL) database	Moderate	+++
<i>Heritage & identity</i>						
Archaeology	**	Number and importance of sites	Two scheduled ancient monuments and fish weirs within the estuary. Also shipwrecks at the mouth, lime kilns and World War II artefacts on the shore.	Preece (2005, 2008)	Good	---
Cultural heritage	***	Value to the community	Strong history of shipbuilding, fishing and maritime trade, which has recently been recorded in oral histories, and features in tourism media	Preece, 2008; Farr, 1976;	Poor	0
<i>Psychological wellbeing</i>						
Ambience (visual amenity, tranquillity)	***	Designations recognising natural beauty Value to the community	The area around the mouth of the estuary is within an Area of Outstanding Natural Beauty	North Devon AONB Partnership, 2009	Poor	+ ³ / - - - ⁴
Inspiration	*	Number/ frequency/ importance of art works	Prose, poetry, visual and performing arts have all been inspired by the estuary	Appledore Arts, 2010	Poor	+ ⁵ / - ⁶
<i>C. Indirect use</i>						
<i>Contaminant control</i>						
Water quality regulation	***	Frequency and severity of contaminant incidents compared to threshold	High levels of <i>E. coli</i> result in the regular downgrading of shellfish beds. 75% of bathing water quality ratings were poor between 1990 and 2010.	UK National Reference Laboratory, unpublished data; Environment Agency, 2010	Good	---
Air quality regulation	*		Unknown		Poor	0
<i>Disturbance prevention</i>						
Flood control	***	Number of properties flooded and frequency of events compared to threshold	There is some degree of manmade flood defence along almost the entire length of the estuary, and so the role of the ecosystem has probably been superseded.	NDC & TDC. 2009a,b; TTEP, 1998	Good	++ + ⁷ / - ⁸
Erosion control	*	Area of land lost compared to threshold			Good	+ ⁹ / - ¹⁰
Climate/weather regulation	*	Incidents of extreme weather compared to threshold	Unknown		Poor	0
<i>D. Additional components of total economic value</i>						
Existence value						
Bequest value	**	Value to the community	Unknown		Poor	-
Option value						

¹ Increasing water level upstream providing longer access

² Barrier to navigation

³ Higher water level increasing view of water (rather than mud)

⁴ Presence of the barrage structure

⁵ New structures and seascapes

⁶ Changes to existing seascapes and noise

⁷ Controls on tidal and fluvial flooding

⁸ Potential groundwater flooding

⁹ Reduced upstream erosion

¹⁰ Increased erosion in the proximity of the barrage

5. Discussion

The basis of the EBA is the inventory of environmental benefits provided by the site. The framework proposed for compiling this inventory (Table 1) attempts to facilitate any ultimate monetary valuation, but its purpose remains the coherent classification of benefits, not the resolution of all potential issues that may arise at the valuation stage. One such issue is the valuation of multiple benefits that are provided by the same service. For example, angling provides benefits from enjoyment of the activity, while any retained catch also provides food, and it may be difficult to disentangle the recreational and psychological benefits and the non-use values associated with regular walks along a coastal footpath. However, it is acceptable to assess (and ultimately value) these divergent benefits separately, providing they are distinct (Fisher and Turner, 2008), and so the comprehensive classification suggested in the framework achieves its purpose of facilitating valuation.

The empirical EBA carried out for a hypothetical tidal barrage in the Taw Torridge demonstrated that the proposed methodology can be successfully employed as a tool for evaluating the changes likely to result from local scale developments. There are, however, some limitations to its application, both in this specific case and more generally. In the case study, there are several gaps in the data, and poor confidence in the accuracy of much of the data that was available. For example, it was not possible to identify all fishers or shellfish harvesters; other fisher data was more than three years old; or aggregated at too large a spatial scale (ICES rectangle level) to attribute benefits derived locally from the estuary; and recreational use was underestimated, particularly in terms of visitor numbers.

This is partly as a result of the desk-based nature of the case study: further empirical research would provide additional information, and the preliminary steps in the EBA serve as a gap analysis to identify required data. If an EBA is to be comprehensive and accurate, it will be necessary to identify all groups of beneficiaries and obtain information that is sufficiently representative of their activities. This will remain problematic where there are many small-scale users whose activities are not routinely recorded and will require comprehensive surveys for example for recreational users and small-scale fishers. The likely variation in data accuracy and availability (even where comprehensive empirical information is available) illustrates the importance of presenting a confidence assessment with the data, so that it can be appropriately weighted during the decision-making process.

There are more systemic issues with the methodology, particularly concerning quantification of some of the cultural benefits. Williamson's novel and other artworks and events attest that the Taw Torridge is a source of inspiration, but there is no obvious means by which to quantify this in the same way as, for example, fish catches or number of recreational users. Quantifying the likely change in inspiration as a result of an intervention is also problematic. Even a development as substantial as a tidal barrage is unlikely to destroy the character of the entire estuary, and the development itself may provide a new

source of inspiration. The ambience (including the visual amenity and tranquillity) of an area is similarly difficult to define and quantify, as is cultural heritage, especially where the traditional industries or activities on which this heritage is based no longer occur and so will not be directly impacted by any modern development.

These practical difficulties suggest that it is unlikely to be possible to include inspiration, ambience and cultural heritage as specific individual benefits within an objective, quantitative EBA. However, it is important that they should not be excluded from environmental benefits inventories. They remain important components of the large and diverse range of benefits provided by the natural environment and, while objective quantification of the level of delivery of these benefits is problematic, there are appropriate (often narrative-based) methods within other social science disciplines to capture the strength and foundation of cultural values. Conceptual frameworks for ecosystem service assessments already acknowledge the difficulties in making quantitative assessments of cultural benefits, and also that simply recognising that cultural value exist may be sufficient to generate policy responses (TEEB, 2010; Daniel et al., 2012). However, at the core of the ecosystem services approach is the intention to improve quantification of the benefits people receive from nature so that social and environmental externalities can be better compared with manmade capital. Reporting cultural services in only qualitative terms brings the risk that they will be overlooked, and so it is important that efforts continue to identify appropriate indicators and metrics for cultural services.

Application of the EBA also revealed a second major issue: attributing aggregate benefits to a local source. With shellfish harvesting, the ecosystem service is provided within the estuary, and the benefit is realised there, so the quantification of benefit delivery and potential impact from the development is relatively straightforward. The situation is more complicated for capture fisheries. Landings at ports within the estuary are recorded, but these do not all originate from the local area, and even where they do, the direct role of the estuary in fisheries production is difficult to readily quantify without complex modelling approaches.

Scale is also an issue when considering the benefits from regulating services. The role of the local environment (in isolation) in providing these benefits is often negligible, and so the impact of a local-scale development may be effectively nil. This is particularly relevant to climate and weather regulation, as it seems highly unlikely that a development on the scale of a tidal barrage in the Taw Torridge will have any discernible effect on local weather patterns. However, the effects of local developments accrue cumulatively at a national level and account must be taken of this. This can be achieved by considering the service underlying the benefit (in this case carbon sequestration) which can be quantified at a local scale. The relative impact of a particular development, and its contribution to the cumulative impacts of other interventions can therefore be determined.

For the purposes of valuation it is justifiable, indeed desirable, to focus on the endpoints of the ecosystem service cascade (Fisher et al., 2008; Boyd and Banzhaf, 2007; Wallace, 2007). However, failure to consider the underlying ecological processes restricts the application of an Environmental Benefits Assessment framework as a broader resource management tool. In management, attempts are made to maintain or modify the delivery of benefit and so it is important to understand the implications of interventions at any stage in the benefit supply chain. Also, by the time changes in the ecosystem are manifested as changes in environmental benefits it may be too late to mediate the impacts that have negatively affected processes at lower levels in the system.

Water quality is one example of the need to understand the level of service delivery in addition to the benefit. The benefit of clean water for bathing or production of shellfish is provided if contaminants are below a certain threshold. However, failure to also monitor the habitats responsible for pollutant sequestration could result in a sudden and unexpected decline in water quality, even where there has been no increase in contaminant input. The EBA methodology as presented does not preclude its expansion to incorporate appropriate indicators of the underlying services that are required to maintain the delivery of marine environmental benefits.

6. Conclusions

The Environmental Benefits Assessment (EBA) methodology proposed provides a systematic approach to evaluating the impacts of local-scale developments on environmental benefits, and the case study of a hypothetical tidal barrage within the Taw Torridge estuary illustrates that the proposed EBA methodology functions well. However, progress is needed in addressing the challenges associated with attempting to objectively quantify the delivery of cultural benefits and issues of scale to better enable fully comprehensive assessment. The proposed focus on benefits (as the endpoints of the ecosystem service cascade) restricts application of EBA as a broader management tool as it excludes information that is highly relevant to managing resources in order to ensure the continued delivery of benefits. Extension of the methodology to include indicators for the marine ecosystem services that provide the environmental benefits remains desirable.

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